

# APPARATUS AND METHOD FOR DRYING SOLUTIONS CONTAINING MACROMOLECULES

Inventors: Abdul H. Ally  
Brent W. Henry  
Michael W. Schuette

## BACKGROUND OF THE INVENTION

### Field of the Invention

[0001] The present invention relates to an apparatus and method for drying solutions containing macromolecules.

### Background Art

[0002] Solutions, such as those used for deoxyribonucleic acid (DNA) synthesis, are often dried for long-term storage. These dried solutions can be reconstituted for use when needed. This technique is particularly useful in areas in which refrigerated storage is prohibitively expensive or unavailable. In these areas, room temperature storage of dried solutions is the only means available to store and use the necessary solutions.

[0003] Conventional devices for drying solutions include vacuum and centrifugal force systems, such as those available from Savant Instruments, Inc., of Holbrook, NY. These devices use a vacuum to increase the rate of evaporation. A vacuum, however, can cause foaming and bumping, resulting in sample loss and contamination of other samples. Moreover, vacuum pumps can be damaged by the solutions being dried and thus require vapor traps. Centrifugal force, generated by spinning the samples, may reduce foaming and bumping. However, mechanisms for spinning the samples include rotors and motors that have to be carefully balanced. Balancing includes loading samples to be dried in prescribed manners. Failure to maintain proper balance can lead to oscillating vibrations that can cause catastrophic failure of rotors and motors. Conventional drying systems can take several hours to dry a set of solutions.

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**[0005]** The present invention is an apparatus and method for quickly drying solutions in large arrays of vessels. The apparatus includes a dryer manifold that holds large arrays of vessels which contain solutions to be dried. The solutions to be dried can include macro-molecules such as ribonucleic acid (RNA), DNA, oligonucleotides, proteins, lipids, carbohydrates, polypeptides, cells, chemical compounds and combinations thereof. Gas, which can be inert gas, air, oxygen, nitrogen, or any other gas or mixture of gasses that are suitable for drying solutions, is provided to the dryer manifold, which directs the gas into the arrays of vessels. Preferably, the gas is pressurized. More preferably, the gas is pressurized and heated. More preferably still, the gas is pressurized, heated and filtered. Preferably, the solutions to be dried are heated. The combination of heating the solutions and directing heated gas over the solutions, quickly evaporates the solutions to be dried. Exhaust vapors are removed from the vessels and is optionally captured by a vapor recovery system.

**[0007]** Preferably the dryer manifold heats the solutions to be dried. For example, the base plate can be heated. In an exemplary embodiment, the base plate receives one or more removable vessel tray that hold a plurality of vessels. The heated base plate heats the solutions in the vessel trays.

## BRIEF SUMMARY OF THE INVENTION

**[0008]** The present invention can employ a variety of types of downwardly extending hollow tubes to provide the gas into the vessels. In an exemplary embodiment, one or more of the downwardly extending hollow tubes include a substantially downwardly-facing opening that directs the gas substantially directly at a surface of a solution in a vessel. In another exemplary embodiment, one or more of the downwardly extending hollow tubes include one or more substantially horizontally-facing openings that direct the gas substantially horizontal to a surface of a solution in a vessel. In another exemplary embodiment, the present invention employs a combination of substantially downwardly-facing openings and substantially horizontally-facing openings.

**[0009]** The present invention can utilize an inlet filter, such as a high extraction particulate air (HEPA) filter, to filter the gas that is provided to the dryer manifold. An inlet fan can be utilized to pressurize the gas and an inlet heater can be utilized to heat the gas. An exhaust fan can be utilized to draw exhaust vapors from the dryer manifold.

**[0010]** In an exemplary embodiment, the base plate is hingedly coupled to the manifold so that the base plate has an open position and a closed position. The open position permits users to place and remove vessels in the dryer manifold. In the closed position, the base plate and the manifold are in sealing engagement with one another. Preferably, when in the closed position, the downwardly extending tubes extend into the vessels without contacting the vessels and contacting the solutions in the vessels.

**[0011]** In an exemplary embodiment, when the base plate is in the closed position, the vessels are tilted at an angle. By tilting the vessels at the angle, the solutions are provided with a greater surface area, which increases the rate of drying.

**[0012]** A unique hinging system is disclosed which hinges each base plate so that is rotates about a pivoting point that is relatively distant from the corresponding manifold. This ensures that the downwardly extending tubes can extend into the vessels when the base plate is moved into the closed position, without the downwardly extending tubes contacting the vessels.

**[0013]** A base can be employed which permits multiple manifold and base plate assemblies to extend therefrom. The base permits the entire dryer manifold to be supported by a small surface area. The present invention is thus highly scalable in that the dryer manifold can include a plurality of manifolds and base plate assemblies. In an exemplary embodiment, the dryer manifold includes two, substantially mirror image, manifold and base plate assemblies, wherein each base plate can hold an array of vessels.

**[0014]** Where multiple manifold and base plate assemblies are employed, a duct system can be utilized to provide gas to the assemblies. One or more inlet heaters can be disposed within the duct system to heat the gas.

**[0015]** The present invention can employ an optional vapor recovery system which recovers exhaust vapors from the one or more vessels that contain solutions to be dried. The optional vapor recovery system can, for example, include a conventional vapor recovery system disposed downstream of the dryer manifold. In addition, or alternatively, the optional vapor recovery system can include a coaxial tube system that prevents exhaust vapors from a vessel from contaminating a solution in another vessel.

**[0016]** In order to control the drying of solutions in vessels, the present invention includes an electrical control system that can adjust the pressure and temperature of the gas and/or the temperature of the solutions to be dried. In an exemplary embodiment, the electrical control system includes one or more open-loop systems, such as manual adjustments, which control the pressure and temperature of the gas and/or the temperature of the solutions to be dried. In another exemplary embodiment, the electrical control system includes one or more closed-loop systems that control temperatures and pressures, based on comparisons of measured values and predetermined values. In another exemplary embodiment, the electrical control system is a combination of open-loop and closed-loop systems.

**[0017]** The present invention can substantially prevent bumping and boiling of the solution in the vessel by controlling the pressure and temperature of the gas and/or the temperature of the solutions, based on the level of solution in a vessel. For

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- [0025] FIG. 4 illustrates a control panel that can be used as part of an open-loop electrical control system, in accordance with the present invention.
- [0026] FIG. 5 illustrates a first perspective view of a dual-chamber dryer manifold and the y-branch duct system, in accordance with the present invention.
- [0027] FIG. 6 illustrates a second perspective view of the dryer manifold illustrated in FIG. 5.
- [0028] FIG. 7 illustrates a third perspective view of the dryer manifold illustrated in FIGs. 5 and 6.
- [0029] FIG. 8 illustrates a vessel tray that can be employed by the present invention.
- [0030] FIG. 9 illustrates a partially sectional view of the dryer manifold taken along a line 9-9 in FIG. 7.
- [0031] FIG. 10 illustrates a partially sectional view of the dryer manifold taken along the line 9-9 in FIG. 7.
- [0032] FIG. 11 illustrates downwardly extending hollow tubes that can be employed by the present invention.
- [0033] FIG. 12 illustrates a vessel in an upright position holding a solution to be dried.
- [0034] FIG. 13 illustrates the vessel of FIG. 12, tilted at an angle  $\alpha$ .
- [0035] FIG. 14 illustrates a perspective view of a hollow, coaxial vapor recovery tube that can be employed in the present invention.
- [0036] FIG. 15 illustrates a partially sectioned view of the hollow, coaxial vapor recovery tube illustrated in FIG. 14.
- [0037] FIG. 16 illustrates a high-level block diagram of a combination open-loop and closed-loop electrical control system, in accordance with the present invention.
- [0038] FIG. 17A is a schematic diagram illustrating a substantially open-loop electrical control system, in accordance with the present invention.
- [0039] FIG. 17B is a schematic diagram illustrating an embodiment of a portion of the schematic diagram illustrated in FIG. 17A.
- [0040] FIG. 18 is a process flow-chart of a method for drying solutions.

- [0041] FIG. 19 illustrates a perspective view of a T-branch duct system that can be employed in the present invention.
- [0042] FIG. 20 is a front plan view of the T-branch duct system illustrated in FIG. 19.
- [0043] FIG. 21 is a top plan view of the T-branch duct system illustrated in FIGs. 19 and 20.
- [0044] FIG. 22 illustrates a perspective view of a small footprint drying system that employs the T-branch duct system of FIGs. 20 and 22.
- [0045] FIG. 23 illustrates a front plan view of the system illustrated in FIG. 22.
- [0046] FIG. 24 illustrates a top plan view of the system illustrated in FIGs. 22 and 23.
- [0047] FIG. 25 illustrates a vapor recovery plate that can be employed to reduce contamination of solutions in vessels.
- [0048] FIG. 26 illustrates an array of vessels that can be used to hold solutions to be dried.

## DETAILED DESCRIPTION OF THE INVENTION

### I. General Overview

- [0049] The present invention is now described with reference to the figures. While specific configurations and arrangements are discussed, it should be understood that this is done for illustrative purposes only. A person skilled in the relevant art will recognize that other configurations and arrangements can be used without departing from the spirit and scope of the invention.
- [0050] In the figures, like reference numbers generally indicate identical, functionally similar, and/or structurally similar elements. The figure in which an element first appears is indicated by the leftmost digit(s) in the reference number.
- [0051] Referring to FIG. 1, a drying system 102 includes a dryer manifold 124 that dries solutions contained in one or more arrays of vessels by directing gas 110, which can be inert gas, air, oxygen, nitrogen, or any other gas or mixture of

gasses that are suitable for drying, into the vessels. The solutions can be, for example, solutions that contain macro-molecules including, but not limited to, DNA, proteins, lipids, carbohydrates, RNA, oligonucleotides, polypeptides, cells, antibiotics, chemical compounds, enzymes (DNA or RNA polymerases such as thermostable DNA polymerases including *Taq*, *Tma*, or *Tne* DNA polymerases, restriction endonucleases, ligases, reverse transcriptases, etc.), antibodies or combinations thereof. The solutions can also be, for example, liquid reagents used in diagnostic applications, assays used in clinical environments or assays used in research applications.

[0052] In an exemplary embodiment, system 102 includes a filter 112, that receives and filters gas 110 to generate filtered gas 114. A fan 116 pressurizes gas 140 to generate filtered, pressurized gas 118. A heater 120 heats filtered, pressurized gas 118 to generate filtered, pressurized, heated gas 122. In this embodiment, gas 110 is provided to dryer manifold 124 as filtered, pressurized, heated gas 122.

[0053] One skilled in the relevant art will recognize that one or more of filter 112, fan 116 and heater 120 can be arranged in a variety of manners. Moreover, one or more of filter 112, fan 116 and heater 120 can be omitted. Thus, throughout the remainder of this disclosure, it is to be understood that the phrases gas 110, gas 114, gas 118, gas 122 and inlet gas are generally used interchangeably. Unless otherwise noted, each of these terms are used broadly to refer to any type of gas, including, but not limited to, filtered gas, pressurized gas, heated gas, etc., or any combination thereof.

[0054] Dryer manifold 124 holds a plurality of vessels (not shown in FIG. 1) which contain solutions to be dried and directs gas 110 into the vessels. In an exemplary embodiment, dryer manifold 124 directs gas 110 substantially toward the surface of the solutions to be dried. In an alternative embodiment, dryer manifold 124 directs gas 110 substantially horizontal to the surface of the solutions to be dried. Gas 110 induces evaporation of the solutions, which generates exhaust vapors 126. The process leaves substantially dry macromolecule substances in the vessels.

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[0058] In an alternative exemplary embodiment, electrical control system 130 is a closed-loop system that receives electrical signals representative of, for example, a pressure of gas 122, a temperature of gas 122 and/or a temperature of dryer manifold 124. The closed loop electrical control system 130 compares one or more of the received signals to signals indicative of, for example, desired pressures and/or temperatures. The closed loop electrical control system 130 can adjust a speed of fan 116, a temperature of heater 120 and/or a temperature of dryer manifold 124, accordingly. In another alternative exemplary embodiment, electrical control system 130 is a combination of open loop and closed loop system.

## II. Example Embodiment

- [0059] Referring to FIG. 2, a high-level block diagram of an embodiment of drying system 102 is illustrated. In this embodiment, dryer manifold 124 is a dual-manifold assembly that includes a front chamber 212 and a rear chamber 214. Chambers 212 and 214 each hold a plurality of vessels (not shown in FIG. 2) that contain solutions to be dried. The vessels can be arranged in a plurality of arrays of vessels. Chambers 212 and 214 receive gas 122 through a duct system 210.
- [0060] Filter 112 is illustrated as a high extraction particulate air (HEPA) filter. HEPA filters are well known in the relevant art. A variety of types of HEPA filters can be employed, as would be apparent to one skilled in the relevant art.
- [0061] Fan 116 is illustrated as a fan blower motor that draws gas 110 through HEPA filter 112 and outputs pressurized, filtered gas 118. Fan blower motor 116 can be a variety of commercially available, off-the-shelf fan blower motors. Alternatively, fan blower motor 116 can be custom designed to desired specifications.
- [0062] One skilled in the relevant art will recognize that a variety of combinations of off-the-shelf or custom HEPA filters 112 and fan blower motors 116 can be employed in the present invention. Conventional, off-the-shelf systems that combine a HEPA filter 112 with a fan blower motor 116 can also be used.
- [0063] Pressurized, filtered gas 118 is provided to duct system 210. Referring to FIGs. 19-21, an exemplary embodiment of duct system 210 is illustrated as a T-branch duct system 1910. T-branch duct system 1910 includes a common branch (T-branch) 1912 that divides filtered, pressurized gas 118 between a front branch 1914 and a rear branch 1916. Branches 1914 and 1916 can be constructed from, for example, three inch diameter flexible silicone duct tubes. Other diameters can be used, as would be apparent to one skilled in the relevant art. Actual dimensions can vary with implementations.
- [0064] A first end 1913 of front branch 1914 can be adjustably coupled to T-branch 1912 by a compression fitting 1920. A second end 1915 of front branch 1914 can be adjustably coupled to an end plate 1918 of dryer manifold 124 by a

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compression fitting 1922. Rear branch 1916 can be coupled between T-branch 1912 and end plate 1918 in a similar fashion.

**[0065]** Referring to FIGs. 22-24, in an exemplary embodiment, T-branch duct system 1910 can be configured so that HEPA filter 112 and/or fan 116 rest on a top plate 2214 of dryer manifold 124 (FIGs. 5-7, 9 and 10). In this embodiment, front branch 1914 includes a pivoting section 2210 that permits front branch 1914 to pivot with respect to end plate 1918. Likewise, adjustable compression fitting 1920 permits T-branch 1912 to pivot with respect to front branch 1914. Rear branch 1916 includes a similar pivoting section 2212. This configuration reduces the overall footprint of system 102.

**[0066]** Referring to FIGs. 3A and 3B, in an alternative exemplary embodiment, duct system 210 is illustrated as a Y-branch duct system 310. Y-branch duct system 310 includes a common branch (Y-branch) 312 that receives and divides gas 118 between a front branch 314 and a rear branch 316.

**[0067]** Referring back to FIG. 2, duct system 210 can include a first heater 120 in a front branch 230 and a second heater 120 in a rear branch 232. Front branch 230 can be front branch 1914 of T-branch duct system 1910 or front branch 312 of Y-branch duct system 310. Rear branch 232 can be rear branch 1916 of T-branch duct system 1910 or rear branch 314 of Y-branch duct system 310. A single heater 120 (not shown) could be provided in front branch 230 and rear branch 232.

**[0068]** Heater(s) 120 can be a variety of conventional, off-the-shelf heaters, such as geometrically-reformable heaters available from Watlow Electrical Manufacturing Co. of St. Louis, MO. Geometrically-reformable heaters can be formed into a variety of shapes, such as a compact coiled nozzle, a straight cable, a flat spiral, a star-wound, etc. Heater(s) 120 can be secured within duct system 210 with a variety of conventionally known techniques, such as bolts, screws, epoxy, etc.

**[0069]** Duct system 210 provides gas 122 to chambers 212 and 214. Duct system 210 provides scalability in that a plurality of drying chambers can be employed to

**[0070]** In an exemplary embodiment, chambers 212 and 214 include heaters 216 and 218, respectively, for heating the vessels. Heaters 216 and 218 can be a variety of conventional, off-the-shelf heaters. For example, heaters 216 and 218 can include tapes, mats, fine-strand resistance wires insulated and enclosed in high-strength, high-temperature-resistant silicone rubber, etc. Silicone rubber heaters are available as tapes and mats from, for example, Cole-Parmer Instrument Company, of Vernon Hills, IL. A silicone heating mat, available from Cole-Parmer as part no. E-03125-50, for example, can be used.

[0072] Electrical control system 130 controls one or more of fan 116 and heaters 120, 216 and 218. Electrical control system 130 can include, for example, one or more dual-zone heater controllers 224 to control heaters 120, 216 and 218. Electrical control system 130 can also include an AC motor controller 228 to control fan blower motor 116.

**[0074]** Electrical control system 130 can include a digital timer 226 to delay sampling of the pressure switch for a predetermined period of time. This provides fan blower motor 116 with the predetermined period of time to get up to speed before electrical control system 130 can declare a low pressure fault.

A. Dryer Manifold 124

- [0075] Referring to FIGs. 5, 6 and 7, dryer manifold 124 is illustrated as a dual-chamber dryer manifold, including front chamber 212 and rear chamber 214. Chamber 214 is a substantially mirror image of chamber 212.
- [0076] FIGs. 5 and 6 illustrate partial cutaway views of dual-chamber dryer manifold 124. Front chamber 212 includes a manifold 510 and a base plate 512.
- [0077] Referring to FIG. 6, base plate 512 can hold one or more vessels 614. In an exemplary embodiment, vessels 614 are held by one or more vessel trays 612. Vessel trays 612 can be removably placed on base plate 512. Referring to FIG. 8, vessel trays 612 can include an array of vessel cavities 810 that receive vessels 614. Vessels 614 can be press-fitted vessels that are held in place by friction. Vessels 614 can be made from, for example, thermoplastics and/or metal and can be, for example thin-walled stainless steel vessels.
- [0078] Referring to FIG. 26, in an embodiment, an array of vessels 614 can be provided as one or more deep-well plates of vessels 2610, such as deep-well plates available from Beckman Instruments, Inc. of King of Prussia, PA. For example, part number 227006 from Beckman Instruments includes an array of twenty-four, one milliliter wells. A lid 2612 can be used to seal vessels 2612 when solutions in deep well plate 2610 are not being dried.
- [0079] Referring back to FIG. 6, base plate 512 can include a recessed portion 616 for receiving one or more of vessels 614, vessel trays 612, deep well plates 2610, etc. Recessed portion 616 can be designed to receive any number vessels 614, vessel trays 612, deep well plates 2610, etc. Vessel trays 612 and deep well plates 2610 can hold any number of vessels 614. Base plate 512 can include a recessed perimeter 622 for receiving a seal, such as a silicone o-ring seal 624.
- [0080] In an exemplary embodiment, dryer manifold 124 heats solutions in vessels 614. For example, base plate 512 can include a heater 216 to heat solutions in vessels 614. Heater 216 can be implemented as, for example, a thin, silicone-sealed heating pad placed in recessed portion 616 so that vessel trays 612 rest

thereon. The heating pad can be connected to an electrical source via leads 618. Alternatively, any other suitable heat source can be used to heat solutions in vessels 614. For example, solutions in vessels 614 can be heated with a radiant heater (not shown), a heating coil embedded within base plate 512 (not shown), etc.

[0081] Base plate 512, vessel trays 612 and/or deep-well plates of vessels 2610 can be fabricated from metals such as aluminum alloys and coated aluminum alloys, from thermoplastics such as polypropylene and that sold by DuPont Co. of DE under the trademark Delrin, etc., or combinations thereof. Where dryer manifold 124 heats solutions in vessels 614, one or more portions dryer manifold 124 are preferably manufactured from materials that do not readily transfer heat (eg., thermoplastics, etc.). This ensures better control over heating of solutions in vessels 614.

[0082] Referring to FIG. 7, dryer manifold 124 includes a base 710. Base 710 is common to front and rear chambers 212 and 214. In the illustrated embodiment, base plate 512 is hingedly coupled to base 710 by hinges 712. Hinges 712 provide dryer manifold 124 (or base plate 512) with an open position and a closed position. In both FIG. 5 and FIG. 6, base plate 512 is illustrated in the open position. In FIG. 7, base plate 512 is illustrated in the closed position. When in the closed position, base plate 512 is sealing engagement with manifold 510.

[0083] In an exemplary embodiment, manifold 510 includes a front wall 714, a rear wall 716, a first end wall 718 and a second end wall 720. In the illustrated embodiment, front chamber 212 has rectangular shape. Alternatively, front chamber 212 can be designed in a variety of other shapes.

[0084] Referring back to FIG. 6, manifold 510 includes a nozzle plate 628 which has an array of passages 630. Manifold 510 also includes a baffle plate 632 that guides gas 110 from an inlet 634 through passages 630. Baffle plate 632 and nozzle plate 628 define a plenum 640 therebetween. Referring to FIG. 10, when base plate 512 is in the closed position, nozzle plate 628 and base plate 512 form a cavity 1010 therebetween.

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[0085] Referring back to FIG. 6, nozzle plate 628 includes hollow tubes 636 extending downwardly from passages 630. Referring to FIG. 10, dryer manifold 124 is designed so that, when base plate 512 is in the closed position, hollow tubes 636 extend into vessels 614, without touching vessels 614 or the solutions therein.

[0086] In operation, gas 110 passes through inlet 634 and into plenum 640, where baffle plate 632 forces gas 110 downwardly through passages 630 and through hollow tubes 636. Preferably, hollow tubes 636 do not extend so far into vessels 614 that they contact the solution to be dried. Instead, gas 110 is emitted under pressure from hollow tubes 636 and passes over the surface of the solutions to be dried. As gas 110 passes over the surface of the solutions to be dried, the solutions evaporate, generating exhaust vapors 126. Exhaust vapors 126 pass through an exhaust passage 1012, into exhaust chamber 220 and out an exhaust 642 (FIG. 6).

[0087] In an exemplary embodiment, baffle plate 632 is at an angle of 14.25 degrees relative to nozzle plate 628. This ensures adequate gas flow through all of passages 630. The angle can, however, be set or adjusted to any suitable angle.

[0088] Referring to FIG. 11, downwardly extending hollow tubes 636 can be fashioned in a variety of designs. In an exemplary embodiment, a hollow tube 636a includes a substantially downwardly directed opening 1110 that directs gas 110 substantially at a surface 1112 of solution 1114. In another exemplary embodiment, a hollow tube 636b, includes one or more horizontally directed openings 1116 that direct gas 110 substantially horizontal to surface 1112. Hollow tube 636b can be employed, for example, to reduce foaming and bumping of solution 1114. Openings 1110 and 1116 can be combined on a single hollow tube (not shown). One skilled in the relevant art will recognize that a variety of other options can be employed as well.

[0089] The present invention can reduce drying times by increasing a surface area of a solution to be dried. Referring to FIG. 12, vessel 614 is illustrated in an upright position. This is the position of vessel 614 when base plate 512 is in the open position, as illustrated in FIGs. 5 and 6. Referring to FIG. 13, vessel 614 is

illustrated tilted at an angle  $\alpha$ . This is the position of vessel 614 when base plate 512 is in the closed position, as illustrated in FIGs. 7, 9 and 10.

[0090] Tilting vessels 614 at an angle increases the surface area of the solution to be dried and thus speeds the drying process. When vessel 614 is upright, as illustrated in FIG. 12, solution 1114 has a surface area 1112a. When vessel 614 is tilted as illustrated in FIG. 13, surface area 1112a increases to 1112b. As is well known to those skilled in the art, increasing the surface area of the solution to be dried in vessel 614 increases the rate of evaporation of the solution 1114. In an exemplary embodiment, base plate 512, and hence vessel tray 612 and vessel 614, are tilted at an angle  $\alpha$  of twenty-five degrees. Alternatively,  $\alpha$  can be any angle so long as solution 1114 does not spill out of vessel 614.

[0091] Through a combination of increasing the surface area 1112 of solutions to be dried, heating solutions to be dried, and directing heated gas over the solutions to be dried, drying times are substantially reduced as compared to conventional systems. For example, the present invention can dry plates of forty-eight vessels, each vessel containing 0.5 ml of aqueous solutions in about forty-five to about sixty minutes. A conventional drying system, such as the type constructed by Savant Instruments, which uses a vacuum pump and centrifuge connected to a refrigerated vapor trap, takes three to four hours to dry the same volumes of aqueous solutions.

#### B. Vapor Recovery

[0092] In an exemplary embodiment of the present invention, a vapor recovery system is used to capture exhaust 126 vapors that are evaporated from solution 1114 and/or that are introduced by gas 110. Referring to FIG. 14, a conventional vapor recovery system 128 can be provided downstream of chamber 220. In addition, or alternatively, coaxial vapor recovery can be employed to prevent exhaust vapors 126 from one vessel 614 from entering another vessel 614 with solutions in another vessel 614. Coaxial vapor recovery can be employed to prevent solution loss and contamination from foaming and

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[0093] Referring to FIG. 25, in an exemplary embodiment, a vapor recovery plate 2510 is disposed with front chamber 212, below and substantially parallel to nozzle plate 628, forming a head space 2512 therebetween. Vapor recovery plate 2510, and passages 2514 therethrough, are designed to reduce or eliminate exhaust vapors 126 from a vessel 614 from entering, and possibly contaminating, another vessel 614. Vapor recovery plate 2510 includes an array of passages 2514, each having a first end 2516 that opens to head space 2512 and a second end 2518 that opens to cavity 1010. The shape and size of second end 2518 substantially matches the shape and size of an opening 812 (FIG. 8) of vessels 614. When base plate 512 is in the closed position, vapor recovery plate 2510 forms a tight, compression-like fit with vessels 614. Hollow tubes 636 extend through passages 2514 so that gas 122 passes from plenum 640, through tubes 636 and into vessels 614. Exhaust vapors 126 rise from vessels 614 through passages 2514 (outside of hollow tubes 636) and into head space 2512. From head space 2512, exhaust vapors 126 exit through exhaust passages 1012.

[0094] Referring to FIG. 14, another exemplary embodiment of a coaxial vapor recovery system includes a coaxial hollow tube 1410 that extends from a nozzle passage 630 (FIG. 6). Coaxial hollow tube 1410 includes a pipette 1414 that can be similar to hollow tubes 636a and/or 636b, illustrated in FIG. 11. Coaxial hollow tube 1410 includes an outer tube, or collar, 1416 having a seat 1418. When base plate 512 is in the closed position, seat 1418 is in sealing engagement with a rim 1420 of vessel 614. In operation, gas 122 enters a top opening 1426 of pipette 1414 and exits pipette 1414 from a lower opening 1422 to interact with surface 1112 of solution 1114. Portions of solution 1114 evaporate as exhaust vapors 126 and exit out of an opening 1424 of collar 1416. Collar 1416 substantially prevents exhaust vapors 126 from other vessels 614 from entering the vessel 614 illustrated in FIG. 14.

[0095] Referring to FIG. 15, a partial cutaway view of nozzle plate 628 and vessel tray 612 is illustrated. Exhaust vapors 126 that exits from exhaust opening 1424a can be captured by a hose 1510 coupled thereto. Alternatively, outer tube 1416

can be embedded within nozzle plate 628, where opening 1424b coincides with a passage 1512, within nozzle plate 628, that leads to exhaust passage 1012.

C. Electrical Control System 130

[0096] Electrical control system 130 controls the drying of solutions in vessels 614 by controlling one or more of the pressure and temperature of gas 122 and the temperature of solutions 1114. In an exemplary embodiment, electrical control system 130 is a closed-loop system that controls one or more of the pressure and temperature of gas 122 and the temperature of solutions 1114, based on comparisons between measured values and predetermined values. In another embodiment, electrical control system 130 is an open-loop system that includes manual adjustments for controlling one or more of the pressure and temperature of gas 122 and the temperature of solutions 1114. In another embodiment, electrical control system 130 is a combination open-loop and closed-loop system.

[0097] Referring to FIG. 16, a high-level block diagram illustrates electrical control system 130 as a combination open-loop and close-loop system 1602. Electrical control system 1602 uses an open-loop portion 1604 to control fan blower motor 116 and a close-loop portion 1606 to control the temperatures of gas 122 and solutions 1114.

[0098] In operation, an alternating current (AC) mains voltage 1608 supplies electrical power to digital timer 226. Digital timer 226 supplies electrical power to solid state AC power controller 1612, which provides power to fan blower motor 116. After a delay, digital timer 226 also supplies electrical power to a pressure switch 1614. The delay permits fan 116 to get up to speed before heat is applied to the system. Pressure switch 1614 is positioned downstream of fan blower motor 116 to measure the pressure of gas 122. When the pressure of gas 122 reaches a predetermined level, pressure switch 1614 closes a circuit that supplies electrical power to programmable interface dual-zone (PID) controller 1616.

**[0102]** Alternatively, electrical control system 130 can employ open-loop heater controllers in place of closed-loop heater controllers 1616. For example, AC-power heater controllers available from Cole-Parmer as part number E-03052-65,

can be employed. One skilled in the relevant art will recognize that any of a variety of open-loop heater controllers can be employed.

**[0103]** Electrical control system 130 can include a variety of optional features. For example, referring back to FIG. 2, in a closed-loop embodiment of electrical control system 130, one or more level detectors 236 can be used to measure the level of solution 1114 in one or more vessels 614. Based on a measured level, electrical control system 130 can control one or more of the pressure and temperature of gas 122 and the temperature of solutions 1114.

**[0104]** For example, when a solution level is at a high level, electrical control system 130 can set the pressure and/or temperature of gas 122 and/or the temperature of solutions 1114 to a low setting. This serves to reduce or prevent loss of solution due to foaming and bumping. When a sufficient amount of the solution dries, as detected by the level detector, the electrical control system can reset the pressure and temperature of gas 122 and the temperature of solutions 1114 to a higher setting.

**[0105]** Still referring to FIG. 2, another optional feature includes one or more moisture sensors 234 that sense the moisture content of solutions 1114. Moisture sensors 234 can be positioned within or downstream of drying chamber 124. Electrical control system 130 can terminate the drying process when the moisture content is reduced to a predetermined level. Alternately, the drying process can be terminated by a timer or can be terminated manually.

**[0106]** Referring to FIGs. 17A and 17B, electrical control system 130 is illustrated as a substantially open-loop control system 1710. The following disclosure includes references to FIG. 4, where a control panel 410 includes a variety of displays and manual adjustments for controlling gas temperature and pressure and solution temperature.

**[0107]** In FIG. 17A, AC power is supplied to a terminal block 1712. AC power can be applied to terminal block 1712 through, for example, a protective fuse 1714 and a manual on/off switch 1716.

**[0108]** A voltage controller 1726 receives AC power from terminal block 1712 and controls fan 116. Voltage controller 1726 can include a manual on/off switch

**[0109]** A second voltage controller 1734 receives AC power from terminal block 1712 and controls the temperature of heating elements 216 and 218 . Second voltage controller 1734 includes a manually adjustable control 1736 that controls heating elements 216 and 218. Manually adjustable control 1736, which is illustrated as control 414 in FIG. 4, can be, for example, an adjustable resistor.

[0111] In FIG. 4, a display 418, which can be a liquid crystal display (LCD), provides a visual indication of the temperature of solutions 1114. A display 420 provides a visual indication of the gas temperature. Panel meters 418 and 420 can be, for example, panel meters available from Cole-Parmer.

**[0113]** Third voltage controller 1742 includes a manually adjustable control 1744 that controls the temperature of heater(s) 120. Manually adjustable control 1744, which is illustrated as control 416 in FIG. 4, can be, for example, an adjustable resistor.

[0114] In another embodiment, relay 1724 can also control AC power to second voltage controller 1734, so that heaters 216 and 218 cannot be energized unless sufficient gas flow is detected by pressure sensor 1720.

[0115] In FIG. 4, controls 412, 414 and 416 permit a user to control the rate of drying of solutions 1114 and to reduce or prevent bumping and boiling of the solutions 1114 by adjusting gas pressure, gas temperature and/or solution temperature. For example, when there is a relatively large amount of a solution 1114 in a vessel 614, the user can set gas pressure, gas temperature and/or solution temperature to low levels. When a sufficient amount of solution 1114 has evaporated, the user can set gas pressure, gas temperature and/or solution temperature to high levels.

[0116] One skilled in the relevant art will recognize that an open-loop electrical control system 130 and a closed-loop electrical control system 130 can be implemented in a variety of fashions using a variety of commercially-available and/or design specific hardware, software, firmware or any combination thereof.

## II. Method for Drying Solutions

[0117] Referring to the process flowchart of FIG. 18, a method for drying solutions is provided. The process is described herein as performed by system 102. It will be apparent to one skilled in the relevant art, however, that the process illustrated in FIG. 18 can be performed by a variety of systems. Thus, operation of the present invention is not intended to be limited to the apparatus described with reference to system 102.

[0118] The process begins at a step 1802, where gas 110 is filtered. Gas 110 can be inert gas, air, oxygen, nitrogen, or any other gas or mixture of gasses that are suitable for drying solutions 1114. Step 1802 can be performed by HEPA filter 112 as illustrated in FIG. 2. Electrical control system 130 can include a filter monitor (not shown) that provides an indication, such as a visual indication, when one or more filter elements (not shown) within filter 112 need to be replaced.

**[0119]** In a step 1804, gas 110 is pressurized by fan 116. Electrical control system 130 can include a pressure switch downstream of fan 116 that can sense under-pressure and over-pressure conditions, so that electrical control system 130 can adjust the speed of fan 116. Steps 1802 and 1804 can be performed by a single, off-the-shelf, combination HEPA filter and fan blower motor.

**[0120]** In a step 1806, gas 110 is heated by one or more heaters 120. Heaters 120 can be located within duct system 210. Electrical control system 130 can include heat sensors downstream of heaters 120 that monitor the temperature of gas 110. A heater controller, such as a PID controller 1616, can automatically adjusts a voltage or current to heaters 120 in order to maintain gas 110 at a desired temperature. Alternatively, heaters 120 can be controlled with a manually adjustable control 1744.

**[0121]** In a step 1808, an array of solution-containing vessels 614 are heated. In an exemplary embodiment, one or more vessel trays 612 are placed on a heated surface of base plate 512.

**[0122]** One skilled in the relevant art will recognized that steps 1802-1808 can be performed in any suitable order. In addition, one or more of steps 1802-1808 can be omitted.

**[0123]** In a step 1810, gas 110, which can be heated, pressurized, filtered gas 122, is directed into vessels 614. For example, in FIG. 6, gas 110 is provided to plenum 640, via inlet 634. Plenum 640 directs gas 110 downwardly through passages 630, through hollow tubes 636 and into solution-filled vessels 614.

**[0124]** In an exemplary embodiment, gas 110 exits hollow tubes 636a and imparts substantially directly upon a surface 1112 of solution 1114. In another embodiment, gas 122 exits hollow tubes 636b substantially horizontal to surface 1112.

**[0125]** In order to increase the rate of evaporation of solution 1114, solution-filled vessels 614 can be tilted at an angle, as illustrated in FIG. 13, to increase the exposed surface area 1112b. In an exemplary embodiment, vessels 614 are tilted at an angle of about twenty-five degrees.

**[0131]** Processing proceeds to, and stops at, step 1814.



### III. Conclusions

[0132] While the invention has been particularly shown and described with reference to preferred embodiments thereof, it will be understood by those skilled in the relevant arts that various changes in form and details can be made therein without departing from the spirit and scope of the invention.

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